Simplified SUSY at Lepton Colliders

Mikael Berggren[1]

[1]DESY, Hamburg

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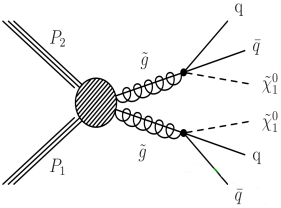
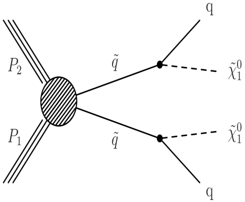
Outline

Simplified SUSY models at LHC

- Simplified models are (very) special cases: the produced SUSY particle goes directly to it's SM partner+MET.
- Either:
  - Production needs a gluino and/or squark in reach.
- Or: Very special spectra
  - EWKinos, sleptons.
  - 3:d gen. squarks.





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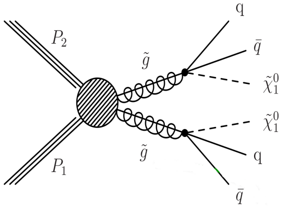

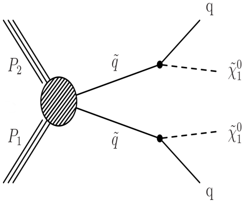

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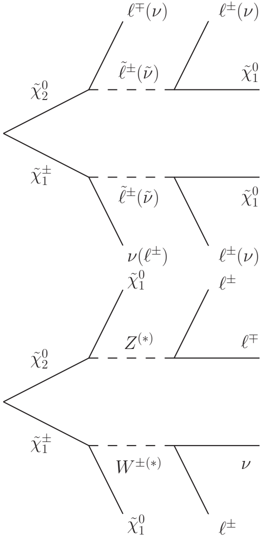

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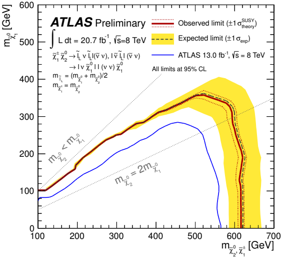

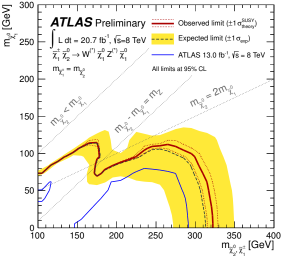

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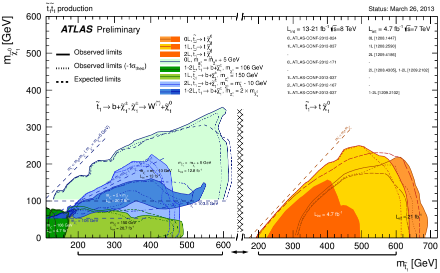

Simplified SUSY models at ILC

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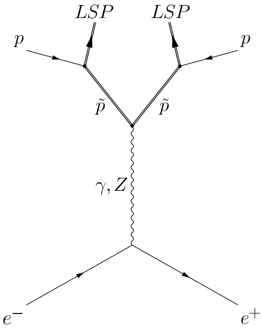
- Obviously: There is one NLSP.



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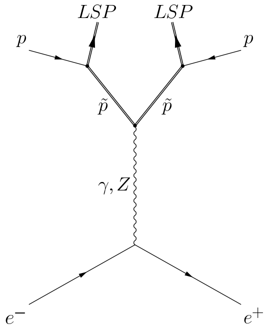

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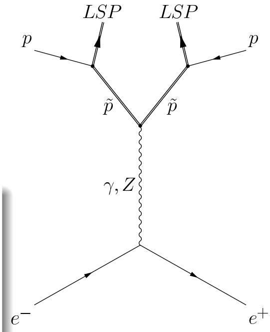
- Cover entire parameter-space in a hand-full of plots
- Cf. LEP !



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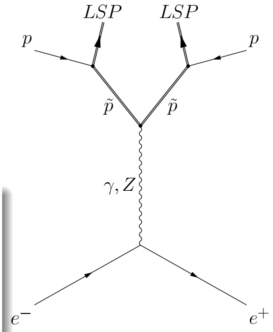

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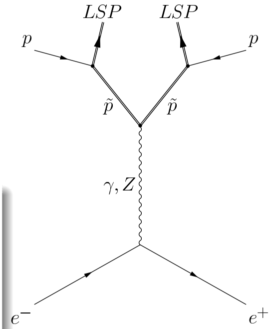

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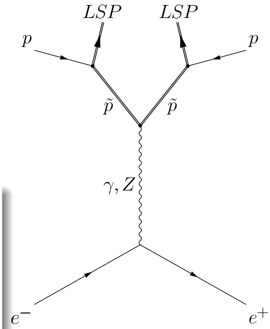

Simplified SUSY models at ILC: But ?

- RPV:
  - If $\exists$ long-lived charged LSP: Even better
  - If $\exists$ long-lived neutral LSP: same as no RPV.
  - If LSP intermediate: decays in detector, also better.
  - If prompt LSP decay: More complex - combinations of λ, λ' and λ'' constrained by other observations $\rightarrow$ lots of cases, with different signatures. Nevertheless; doable.
- Mixed sparticles:
  - sfermion NLSP: One more parameter. NB: one can't mix away $e^+e^- \rightarrow \tilde{f}\tilde{f}$ completely: Coupling to Z might vanish, but not to γ (exception: $\tilde{e}$)
  - bosino NLSP: Back up one step and evaluate limiting cross-sections instead.
- Very low $\Delta(M)$
  - ISR trick.
  - If $E_{CMS} >>$ threshold: boost.
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- Degeneracy, ie $>$ 1 NLSP:
  - No problem for sleptons, sbottom, stop (separable experimentally)
- Side remark: Many open channels, ie if SUSY is main background to SUSY:
  - When data starts coming in, what is is first light ?
  - How do we quickly determine a set of approximative model parameters ?
  - What is then the optimal use of beam-time in such a scenario ?
  - And in a staged approach ?
  - Spectrum in continuum vs. threshold-scans?
  - Special points, eg. between $\tilde{\tau}_1\tilde{\tau}_2$ and $\tilde{\tau}_2\tilde{\tau}_2$ thresholds.
  - Clean vs. high cross-section.
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Method

- "Parameter" scan:
  - Scan $M_{NLSP} - M_{LSP}$ plane.
  - σ from SUSY-principle and kinematics.
- Do FullSim in $\mathcal{O}$(a few) points.
- Tune FastSim to these.
- Then FastSim over a grid.
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Then:

- If $> 5\sigma$: the point is within Discovery Reach.
- If $< 5\sigma$, but $> 2\sigma$: the point is within Exclusion Reach.

In practice: LEP

- See http: //lepsusy. web. cern.ch/ lepsusy/
- Sleptons ...
- Squarks ...
- Bosinos ...

These are combined results; there's more in the results of the individual experiments:

- Aleph squarks: What if ... ?
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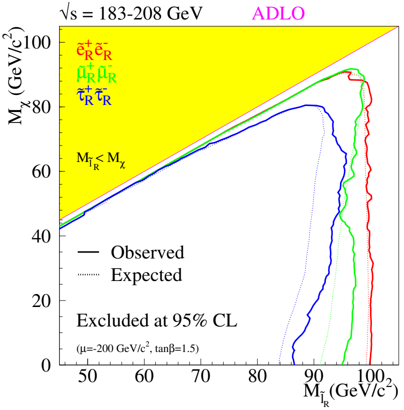

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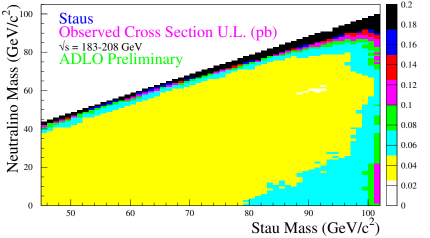

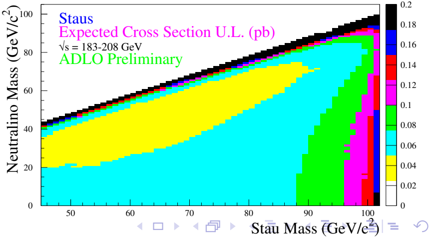

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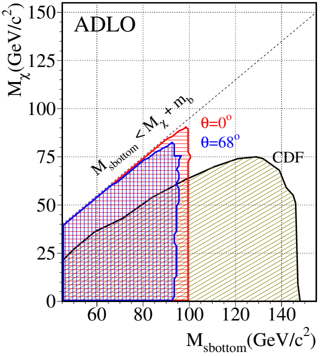

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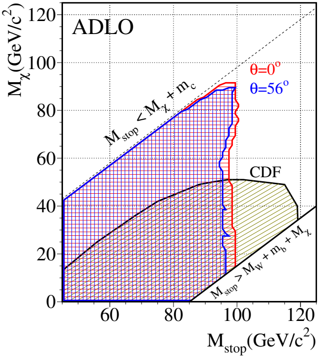

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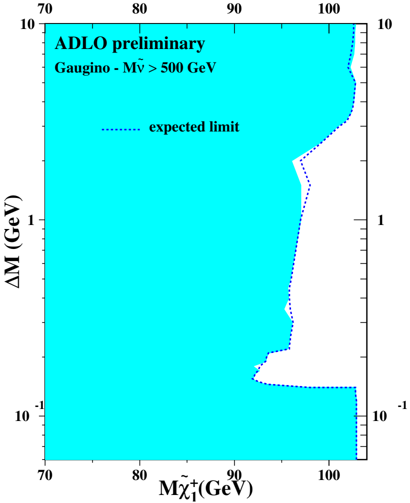

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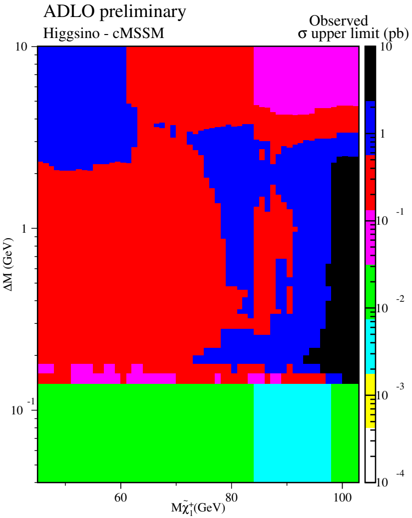

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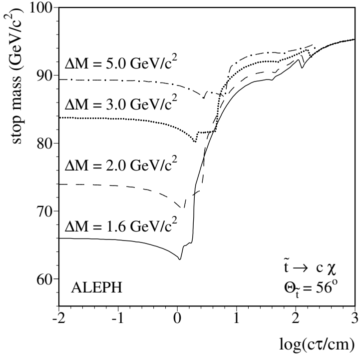

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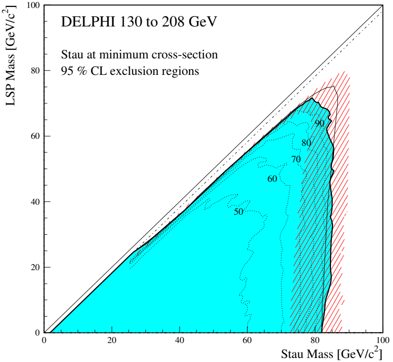

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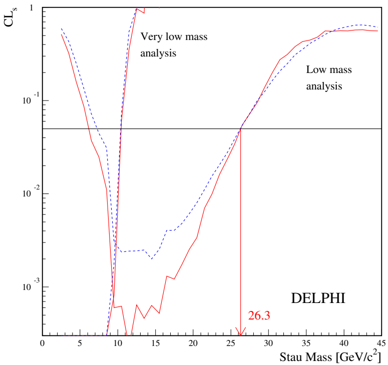

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Bottom line:

VERY hard to wriggle out of this !

- Aleph squarks: What if ... ?
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Some results

- Example from existing FullSim and/or FastSim studies:
  - Sleptons, some bosinos in a specific point.
  - Here: $\tilde{e}_R$,$\tilde{\mu}_R$,$\tilde{\tau}_1$.
  - Example of the last issue - many open channels.
- Use this to
  - Choose running scenario.
  - Tune FullSim and FastSim to agree ?
- ... then start scanning

$\tilde{e}_R$

Early discovery channel:
cross-section in the pb-range.

- Few simple cuts.
  - $E_{vis} < 400$ GeV ($=E_{CMS} - 2M_{\tilde{\chi}^0_1\, min,LEP}$).
  - 2 charged particles
  - $<$ 40% of E_{vis} $<$ below 30 degrees.
- Simple observable: E_{vis}: Peak and width gives $M_{\tilde{e}_R}$ and $M_{\tilde{\chi}^0_1}$.
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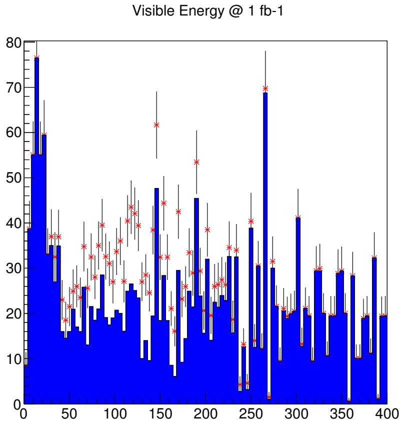

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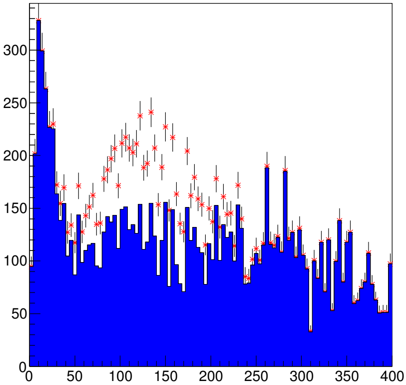

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Early discovery channel:
cross-section in the pb-range.

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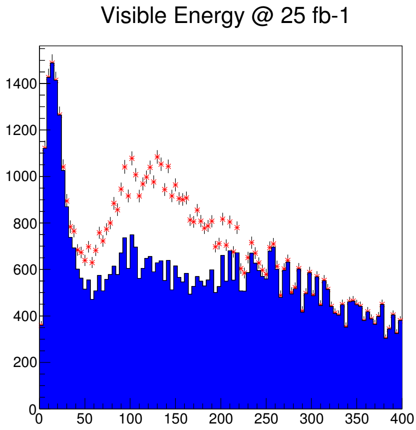

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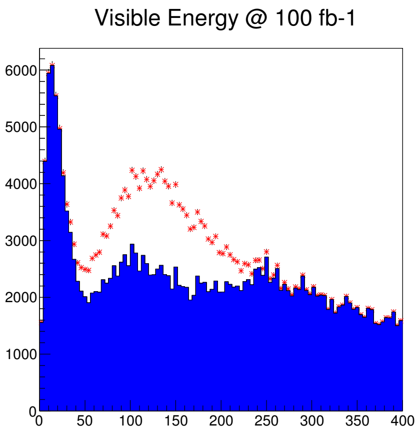

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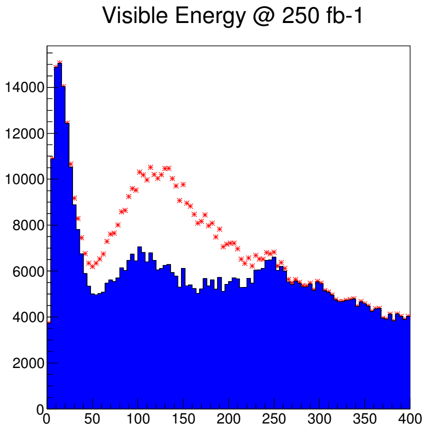

$\tilde{e}_R$ spectrum

- So, within months after start-up, we can estimate $M_{\tilde{e}_R}$ and $M_{\tilde{\chi}^0_1}$ to within a few GeV.
- Use this knowledge for better selection cuts.
- Probably, we have also seen the $\tilde{\mu}_R$.
- ... and that it has ≈ the same mass. as the $\tilde{e}_R$

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Refine cuts for $\tilde{e}_R$ and $\tilde{\mu}_R$

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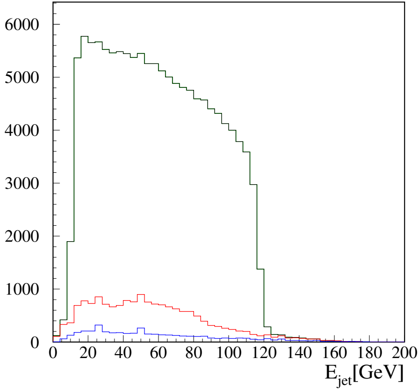
Refine cuts:

- $E_{vis} < 300$ GeV.
- $M_{miss} > 250$ GeV.
- E below 30 degrees < 10 GeV.
- $\cos\theta_{miss} < 0.95$.
- Exactly two opposite charged identified e:s.
- $(E_{jet1} + E_{jet2})\sin\theta_{acop} > 21$, < 135 GeV.

Efficiency 52 %



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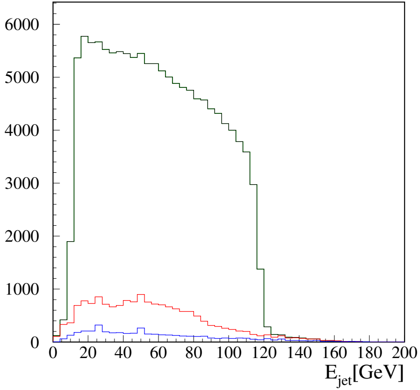

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Same cuts, but ask for two μ:s instead, ie.:

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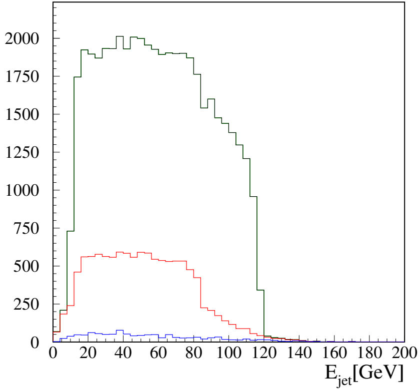

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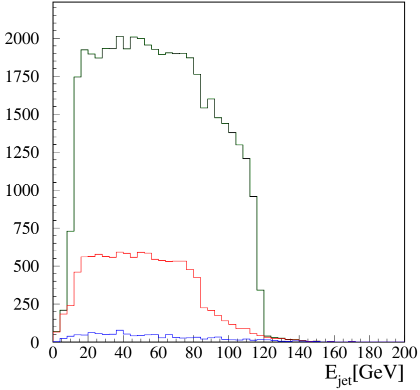

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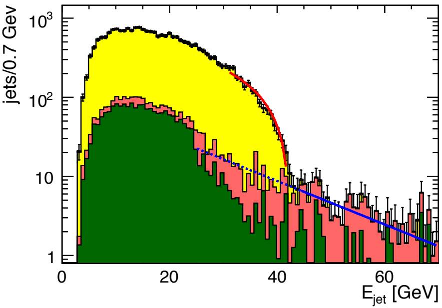
$\tilde{\tau}_1$ spectrum

- $E_{vis} < 300$ GeV.
- $M_{miss} > 250$ GeV.
- Exactly two opposite charged jets identified w. mass < 2.5 GeV.
- No particle with P > 180 GeV.
- $(E_{jet1} + E_{jet2}) \sin\theta_{acop} < 30$ GeV.

Efficiency 15 %



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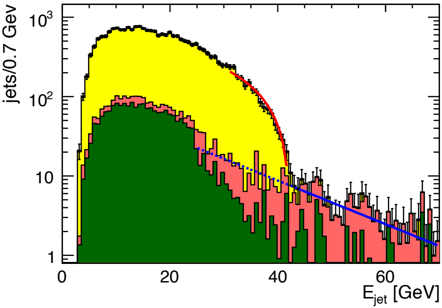

Conclusions and Outlook

- Simplified methods at hadron and lepton machines are different beasts.
- At lepton machines they are quite model independent, as all possible NLSP's can be exploited in a series 2-dim scans
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Work in progress.
Stay tuned.

Thank You !

Backup

BACKUP SLIDES

A New bench-mark point

Remember, apart from naturalness:

- Anomaly in $g-2$ of the μ: Would prefer a not-too-heavy smuon.
- Dark matter : A WIMP of $\sim 100\ \mathrm{GeV}$ would be required.
- EW symmetry breaking, coupling constant unification: points to NP at or below 1 TeV
- Suppress the SUSY flavour problem (FCNC:s etc): Heavy 1:st & 2:nd generation squarks would be nice ...
- Other low-energy constrains : $b \to s\gamma$, $b \to \mu\mu$, ρ-parameter, $\Gamma(Z)$ ...

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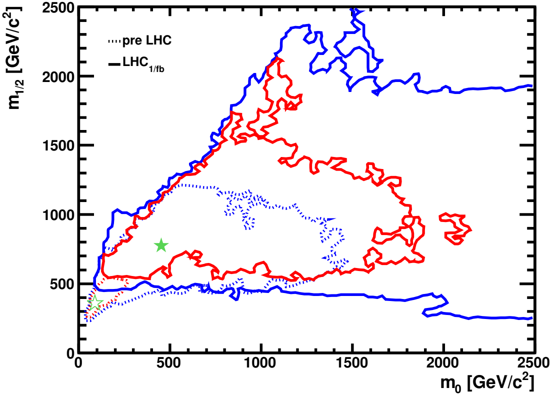
Remember: Without LHC Sps1a' is the best fit!



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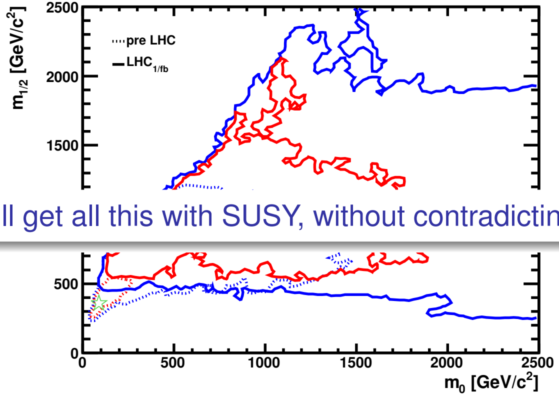

Can we still get all this with SUSY, without contradicting LHC limits ?!

(From Mastercode).

New points

Can all this be provided by SUSY ?Yes, sure !

Take old ILC favourite benchmark SPS1a, and make the TDR4 point (see Baer&List arXiv:1205.6929v1

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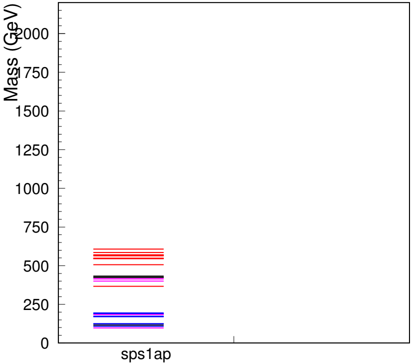

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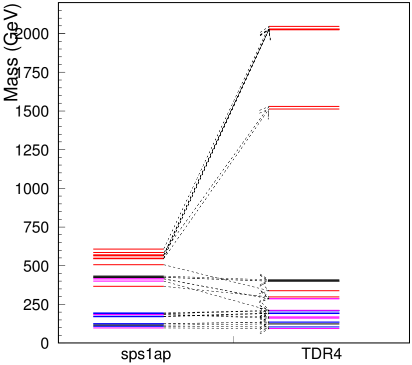

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SPS1a: mSUGRA

- 5 parameters.
- One gaugino parameter
- One scalar parameter

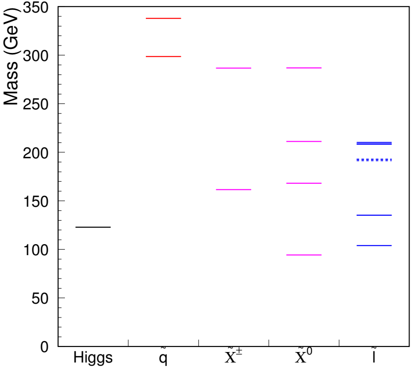
TDR4: Phenomenological SUSY

- 11 parameters.
- Separate gluino
- Higgs, un-coloured, and coloured scalar parameters separate

Parameters chosen to deliver all constraints, $\approx$ same ILC accessible spectrum $\Rightarrow$ old analyses still valid !

Features of TDR 4

- The $\tilde{\tau}_1$ is the NLSP.
- For $\tilde{\tau}_1$: Small Δ_M, $\gamma\gamma$ - background
- For $\tilde{\tau}_2$: $WW \rightarrow l\nu l\nu$ - background $\Leftrightarrow$ Polarisation.
- $\tilde{\tau}$ NLSP $\rightarrow$ τ:s in most SUSY decays $\rightarrow$ SUSY is background to SUSY.
- For pol=(-1,1): $\sigma(\tilde{\chi}_2^0\tilde{\chi}_2^0)$ and $\sigma(\tilde{\chi}_1^+\tilde{\chi}_1^-)$ = several hundred fb and BR(X$\rightarrow$ $\tilde{\tau}$) $>$ 50 %. For pol=(1,-1): $\sigma(\tilde{\chi}_2^0\tilde{\chi}_2^0)$ and $\sigma(\tilde{\chi}_1^+\tilde{\chi}_1^-) \approx 0$.



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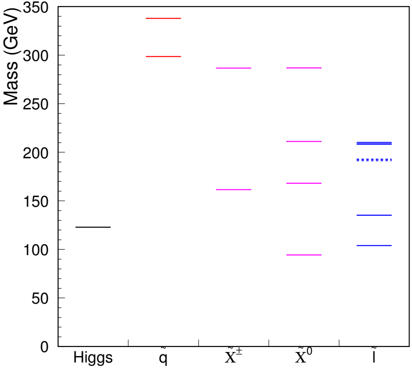
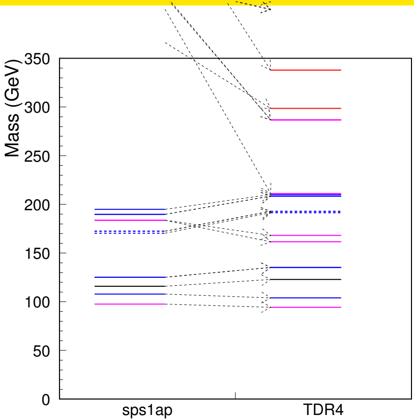


Differences TDR4 - SPS1a'



- All bosinos
- M_h OK
- $\tilde{\ell}_L \to \tilde{\chi}_0^0 \ell$ at 30-40 % BR.

- $\tilde{\chi}_4^0$ and $\tilde{\chi}_2^\pm$ too heavy
- M_h too small
- $\tilde{\ell}_L \to \tilde{\chi}_0^0 \ell$ at $\sim$ 95 % BR.

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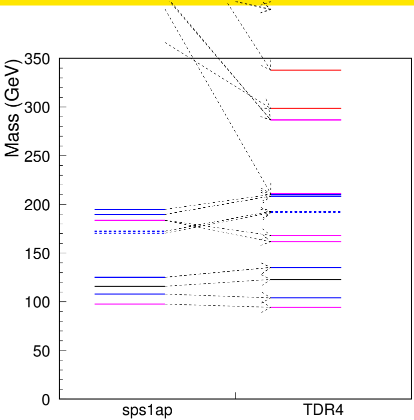

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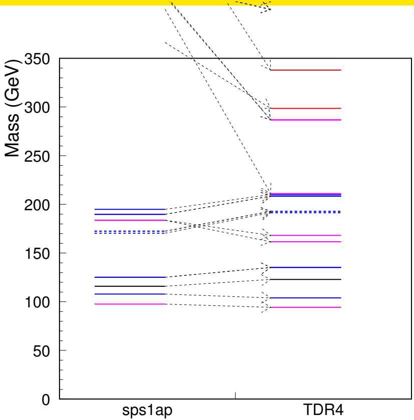

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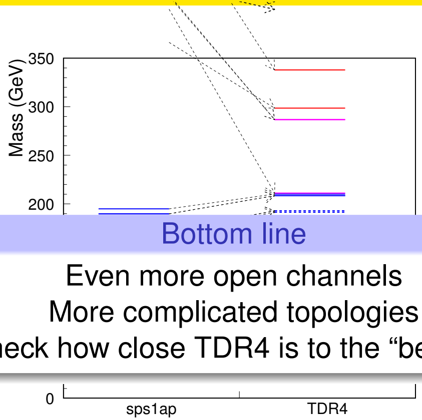

Bottom line

Even more open channels
More complicated topologies
We plan to check how close TDR4 is to the "best fit" (with fittino

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Analysis

Disclaimer

- Very preliminary
- Mostly taken over SPS1a' analyses: Guaranteed to have bad efficiency for heavier states, due to the increase of cascade decays (mostly ignored in Sps1a')

Take over SPS1a' (Phys.Rev.D82:055016,2010, Nicola's thesis,...)

Lighter sleptons

Use the polarisation (0.8,-0.3) of the data to reduce bosino background. Assumed to be 50 % of all data.

From decay kinematics:

- $m_{\tilde{\ell}}$ and $M_{\tilde{\chi}_1^0}$ and end-points of spectrum = $E_{\ell,min(max)}$.
- For $\tilde{\tau}_1$: other end-point hidden in $\gamma\gamma$ background:Must get $M_{\tilde{\chi}_1^0}$ from other sources. ($\tilde{\mu}$, $\tilde{\mathrm{e}}$, ...)

$m_{\tilde{\ell}}$ also from cross-section:

- $\sigma_{\tilde{\ell}} = A(\theta_{\tilde{\ell}}, \mathcal{P}_{beam}) \times \beta^3/s$, so
- $m_{\tilde{\ell}} = E_{beam}\sqrt{1-(\sigma s/A)^{2/3}}$: no $M_{\tilde{\chi}_1^0}$!

From decay spectra:

- $\mathcal{P}_\tau$ from exclusive decay-mode(s): handle on mixing angles $\theta_{\tilde{\tau}}$ and $\theta_{\tilde{\chi}_1^0}$

Topology selection

Take over SPS1a' $\tilde{\tau}$ analysis principle

$\tilde{\ell}$ properties:

- Only two particles (possibly τ:s:s) in the final state.
- Large missing energy and momentum.
- High Acolinearity, with little correlation to the energy of the τ decay-products.
- Central production.
- No forward-backward asymmetry.

+ anti $\gamma\gamma$ cuts (see backup)

Select this by:

- Exactly two jets.
- $N_{ch} < 10$
- Vanishing total charge.
- Charge of each jet = $\pm$ 1,
- $M_{jet} < 2{:}5\ \mathrm{GeV}/c^2$,
- E_{vis} significantly less than E_{CMS}.
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$\tilde{\mu}_{\mathrm{R}}$ threshold scan

From these spectra, we can estimate $M_{\tilde{\mathrm{e}}_{\mathrm{R}}}$, $M_{\tilde{\mu}_{\mathrm{R}}}$ and $M_{\tilde{\chi}^0_1}$ to < 1 GeV.

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So: Next step is $M_{\tilde{\mu}_{\mathrm{R}}}$ from threshold:

- 10 points, 10 fb^{-1}/point.
- Luminosity $\propto E_{CMS}$, so this is $\Leftrightarrow$ 170 fb^{-1} @ E_{CMS}=500 GeV.

Error on $M_{\tilde{\mu}_{\mathrm{R}}}$ = 197 Mev

$\tilde{\mu}_R$ threshold scan

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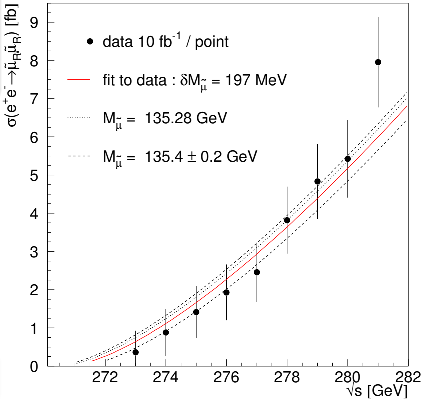

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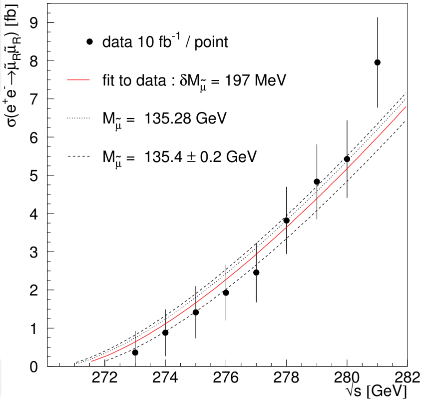

$\tilde{\tau}_1$ (SPS1a')

- $E_{vis} < 300$ GeV.
- M_{miss} > 250 GeV.
- Exactly two opposite charged jets identified w. mass < 2.5 GeV.
- No particle with P > 180 GeV.
- $(E_{jet1} + E_{jet2}) \sin\theta_{acop} < 30$ GeV.

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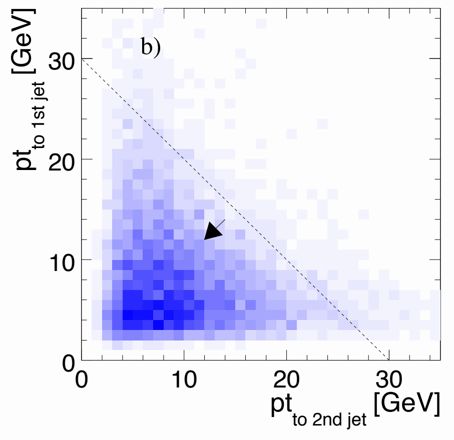

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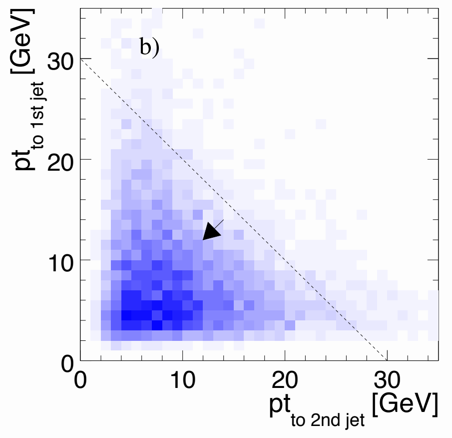

Fitting the $\tilde{\tau}_1$ mass (SPS1a')

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- Background subtraction:
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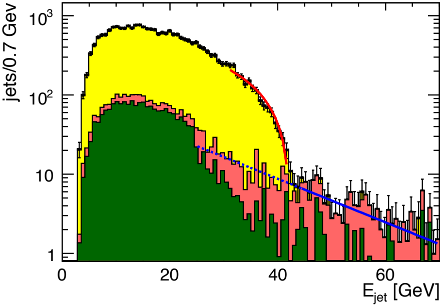

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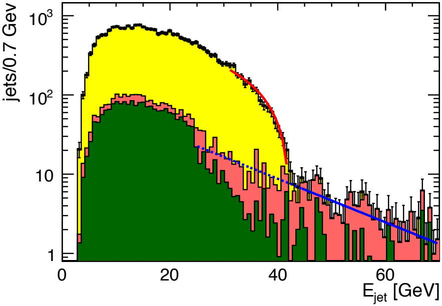

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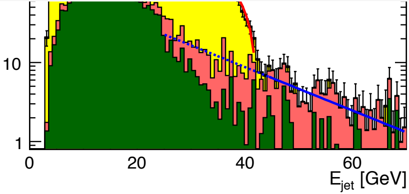

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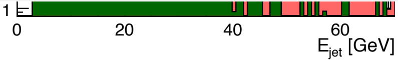
Results from cross-section for $\tilde{\tau}_1$

$\Delta(N_{signal})/N_{signal} = 3.1\% \rightarrow \Delta(M_{\tilde{\tau}_1}) = 3.2\mathrm{GeV}/c^2$



First look at Heavier sleptons ($\tilde{\mu}_{\mathrm{L}}$)

Remember

demanding exactly 2 objects kills 90 % of the signal in TDR4, due to cascaded decays !

- Same cuts as for $\tilde{\mu}_{\mathrm{R}}$, and
- anti-WW likelihood, take over from SPS1a'
- select using other particle: p(other μ) > 120 GeV.

Efficiency 1.5 % (!), $S/B = 0.2$.

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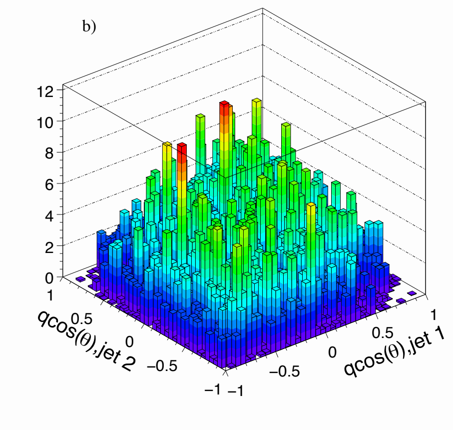

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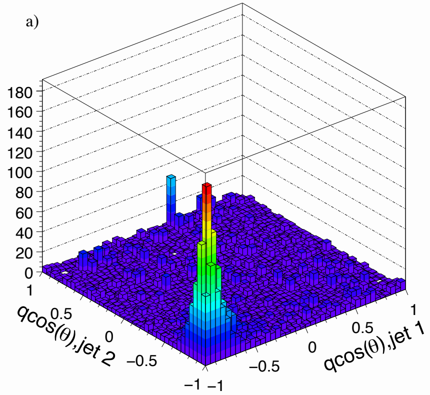

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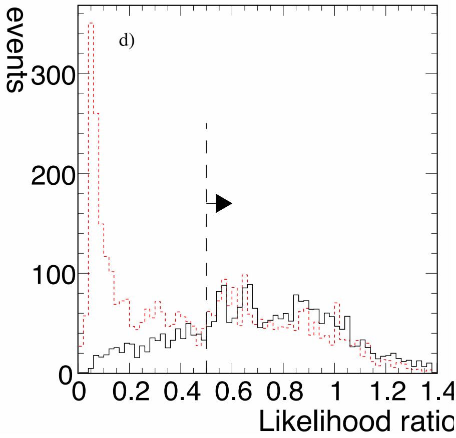

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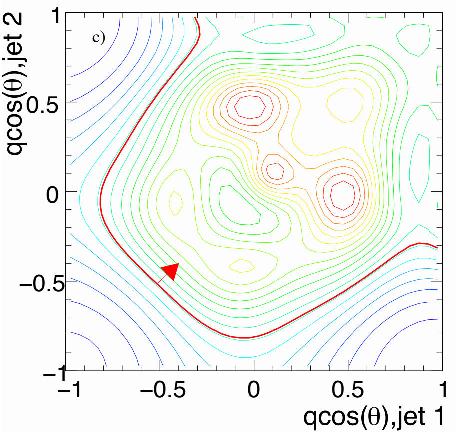

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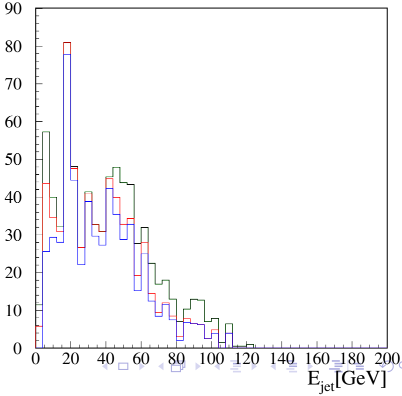

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